Fermilab

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MEASUREMENTS OF SATELLITE REFRIGERATOR COMPRESSOR POWER CONSUMPTION AND EFFICIENCY

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Each of the thirty compressors installed around the ring and at switchyard is an oil-injected, two-stage, Mycom screw compressor, driven by either a 350 hp or 400 hp motor. The reader is referred to TM1198 by John Satti for a detailed description of these compressors and the associated equipment.

Since the power consumed by these compressors is a major operating expense for our accelerator, we were interested in measuring the power consumption and efficiency of our compressors. Two compressors were studied in detail - one having a GE 350 hp motor (FØ #2) and one a new GE 400 hp high efficiency motor (FØ #1).

Data was taken for each compressor with the high stage always fully loaded. These data and values calculated from the data are tabulated in Table 1 for FØ #1 and Table #2 for FØ #2. Each row in the tables resulted from a different low stage slider valve position.

The values in each column of Table 1 and Table 2 were found as follows. Helium temperature was the temperature of the compressor suction pipe about three feet from the compressor. Figures 1a, 1b, and 1c show how the voltage, current, and power factor were measured. Voltage and current were measured using a Fluke Model 8060A D.V.M. Power factor was measured using an Epic Model cosØ 51-D. Electric motor efficiency for the GE 400 hp motor (FØ #1) was found by interpolating test test data for that motor provided by General Electric. For the 350 hp motor an estimate of efficiency at full load provided by General Electric was used with the assumption that the efficiency versus load curve was offset from the 400 hp curve by the difference in full-load efficiencies. Thus, the 350 hp motor is assumed to be 1.7% less efficient than the 400 hp motor for all loads.

Shaft horsepower was calculated from shaft horsepower =

$$\frac{(\text{voltage})\ (\text{current})\ (\text{power factor})\ (\text{motor efficiency})\ (\sqrt{3})}{746\ \text{watts/hp}}$$

Helium flow was calculated from the measured pressure drop through a 0.700 inch diameter orifice in the 2-inch discharge pipe. The pressure drop was measured as shown in Fig. 2a by an ITT Barton model 752 Electronic Differential pressure indicator located in the compressor discharge piping. The output of this device was read by a Fluke DUM and recorded.

The value in inches of water was converted to mass flow, corrected for helium temperature and pressure, from

$$\dot{m}\ (\text{grams/sec}) = 6\sqrt{\left(\Delta P\ (\text{inches})\right)\left(\frac{\text{abs press (psia)}}{294\ \text{psia}}\right)\left(\frac{300^{\circ}\text{K}}{\text{abs temp } (^{\circ}\text{K})}\right)}$$

Throughput was varied by manually adjusting the low stage slider and reading a linear potentiometer that is attached to the slider. (See Fig. 2b.)

The ideal isothermal work was calculated using the formula

$$W = \dot{m}\, RT_1 \ln \ (P_2/P_1)$$

where P_2 is measured discharge helium pressure, P_1 is measured inlet helium pressure, T_1 is measured helium inlet temperature, R is the ideal gas constant for helium (2.08 j/g$^{\circ}$K), and $\dot{m}$ is the measured mass flow rate. The assumption that helium behaves as an ideal gas is good to within 1/2% for this work calculation at these temperatures and pressures.

Isothermal efficiency is defined as ideal isothermal work divided by compressor shaft input power, which is motor shaft horsepower. Thus, the isothermal efficiency is the efficiency of the compressor alone. Inefficiency of the electric motor and power consumed by the oil pump are not included in the isothermal efficiency.

The results are that FØ #1 and FØ #2 both have fully loaded isothermal efficiencies of 40%, and this efficiency drops off to between 20% and 25% with the low stage completely unloaded. Power consumption is not significantly different for these two compressors.

Many different graphs can be made from the data in Tables 1 and 2. We have plotted compressor efficiency versus percent loaded (Fig. 3), helium mass flow versus percent loaded (Fig. 4), and helium mass flow versus electric power consumed (Fig. 5).

TABLE I

DATA FOR FO #1 COMPRESSOR WITH A 400 HP MOTOR

Helium Inlet Temp. (°F)	Power Factor	Motor Current (amps)	Motor Voltage (volts)	Electric Power (HP)	Motor Efficiency (%)	Motor Shaft Power (HP)	Low Stage Slider Position (%)	Helium Flow (g/s)	Helium Inlet Pressure (psia)	Helium Discharge Pressure (psia)	Ideal Gas Isothermal Work (HP)	Isothermal Efficiency (%)
89	.89	401	461	382	95.4	364.4	100	59.7	18.0	309.5	144.27	39.6
89	.89	392	461	373	95.4	356.2	99	56.1	18.1	307.5	135.06	37.9
89	.88	356	461	335	95.4	320.0	98	48.2	18.1	306.5	115.91	36.2
89	.88	350	461	330	95.4	314.5	97	46.6	18.0	306.5	112.28	35.7
89	.875	341	461	320	95.4	304.7	96	45.8	18.1	304.5	109.88	36.1
89	.87	335	461	312	95.4	297.6	95	44.7	18.0	304.5	107.45	36.1
89	.87	331	461	308	95.4	294.0	94	44.2	18.0	303.5	106.12	36.0
89	.865	328	461	304	95.4	289.7	93	43.3	18.0	303.5	103.96	35.8
89	.865	326	461	301	95.2	287.3	92	42.3	18.0	303.5	101.56	35.3
89	.865	326	461	301	95.2	287.3	91	41.9	18.0	303.5	100.60	35.0
89	.86	324	461	298	95.2	283.9	90	41.8	18.0	303.5	100.36	35.3
89	.86	318	461	293	95.2	278.7	85	39.3	18.0	303.5	94.36	33.9
89	.86	315	461	291	95.2	276.6	80	38.3	18.0	303.5	91.96	33.2
89	.855	302	462	277	95.2	263.7	75	35.9	18.1	302.5	85.92	32.6
89	.855	301	462	276	95.2	262.8	70	34.1	18.1	301.5	81.62	31.1
89	.85	284	462	259	95.2	246.5	65	31.1	18.1	301.5	74.35	30.2
89	.845	275	462	250	95.2	237.3	60	30.9	18.0	301.5	74.01	31.2
89	.84	262	462	237	93.0	220.0	50	27.5	18.0	301.5	65.99	30.1
89	.84	253	462	228	93.0	212.0	40	25.3	17.9	301.5	60.84	28.7
89	.83	246	462	219	93.0	203.7	30	22.3	17.9	301.5	53.62	26.3
89	.80	235	462	202	93.0	187.5	20	19.1	18.0	301.5	45.83	24.4
89	.80	230	462	197	93.0	183.5	10	17.6	18.2	301.5	42.07	22.9

TABLE II

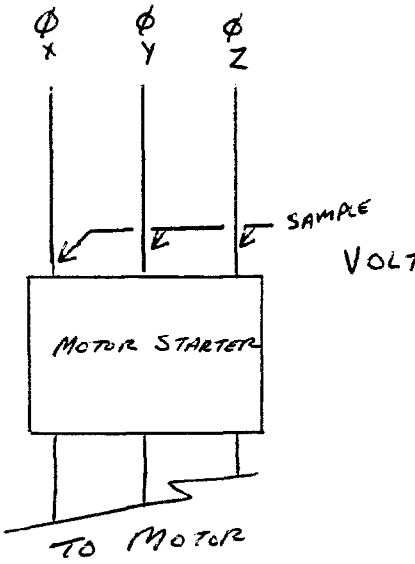
DATA FOR FO #2 COMPRESSOR WITH A 350 HP MOTOR

Helium Inlet Temp. (^oF)	Power Factor	Motor Current (amps)	Motor Voltage (volts)	Electric Power (hp)	Motor Efficiency (%)	Motor Shaft Power (HP)	Low Stage Slider Position (%)	Helium Flow (g/s)	Helium Inlet Pressure (psia)	Helium Discharge Pressure (psia)	Ideal Gas Isothermal Work (hp)	Isothermal Efficiency (%)
106	.92	385	462	380.1	93.7	356.0	100	56.8	17.1	312.5	144.6	40.6
106	.915	328	462	322.1	93.7	301.6	99	44.7	16.9	309.5	113.9	37.8
106	.92	319	462	315.0	93.7	295.0	98	43.1	17.1	309.5	109.4	37.1
106	.915	320	462	314.2	93.7	294.3	97	43.2	16.8	306.5	109.9	37.3
106	.915	309	462	303.4	93.7	284.2	96	41.7	16.9	305.5	105.8	37.2
106	.915	306	462	300.5	93.7	281.4	95	41.0	16.9	305.5	104.0	36.9
106	.91	302	462	294.9	93.7	276.2	94	40.5	17.1	305.5	102.3	37.0
106	.91	301	462	294.0	93.7	275.3	93	39.9	17.1	306.5	100.9	36.6
109	.91	299	462	292.0	93.5	272.9	92	39.4	17.2	306.5	99.97	36.6
109	.91	298	462	291.0	93.5	271.9	91	38.9	17.2	305.5	98.60	36.2
109	.91	298	462	291.0	93.5	271.9	90	38.5	17.2	305.5	97.58	35.8
109	.91	291	462	284.2	93.5	265.6	85	36.5	17.2	305.5	95.04	35.6
109	.90	285	462	275.3	93.5	257.2	80	35.1	17.2	305.5	88.07	34.2
109	.90	275	462	265.6	93.5	248.2	75	33.3	17.2	305.5	84.40	34.0
109	.89	271	462	258.9	93.5	241.9	70	32.6	17.2	306.5	82.72	34.1
110	.89	258	462	246.4	93.5	230.3	60	29.3	17.2	306.5	74.47	32.3
110	.89	240	462	229.2	91.3	209.2	50	25.4	17.2	304.5	64.40	30.8
110	.89	225	462	214.9	91.3	196.1	40	22.9	17.2	304.5	58.10	29.6
110	.89	220	462	210.1	91.3	191.7	30	20.4	17.2	304.5	51.7	26.9
110	.88	206	462	194.6	91.3	177.5	20	18.1	17.2	303.5	45.8	25.8
110	.88	197	462	186.1	91.3	169.8	10	16.0	17.2	303.5	40.5	23.8
112	.87	192	462	179.3	91.3	163.6	0	14.3	17.2	303.5	36.4	22.2

FIGURE 1

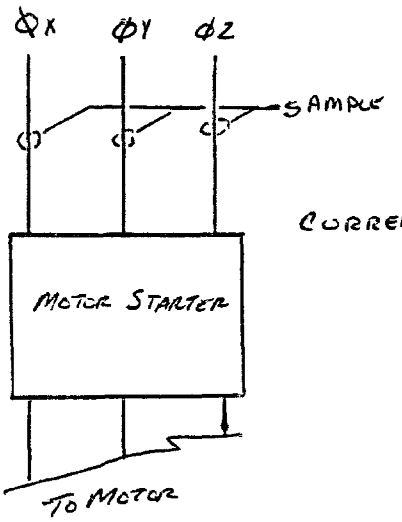
Voltage, Current, and Power Factor Measurements

a.



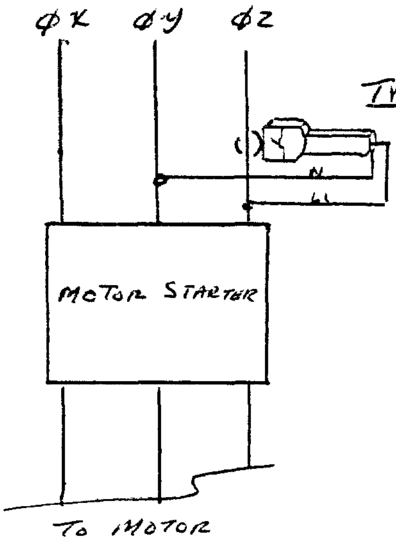
$$\text{VOLTAGE} = \frac{E_{X-Y} + E_{Y-Z} + E_{X-Z}}{3}$$

b.



$$\text{CURRENT} = \frac{I_X + I_Y + I_Z}{3}$$

c.



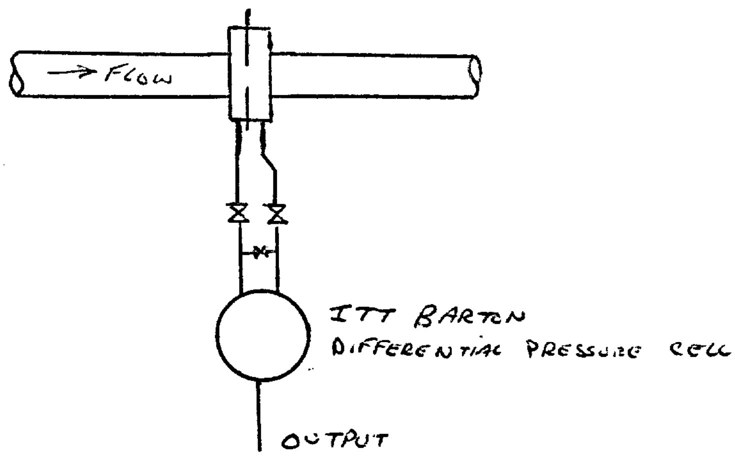
TYPICAL

EPIC COSϕ510 POWER FACTOR METER

FIGURE 2

Flow and Slider Position Measurements

a.



b.

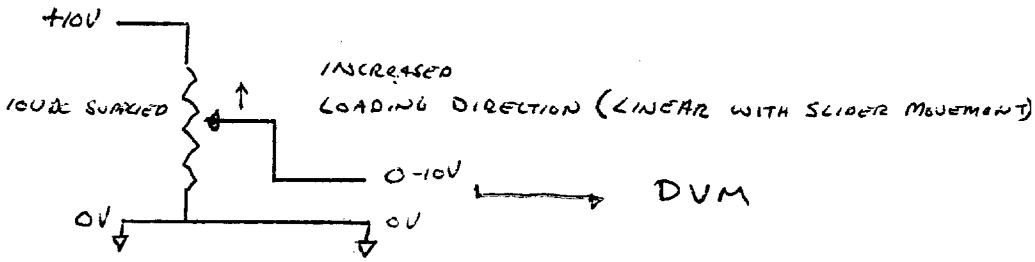
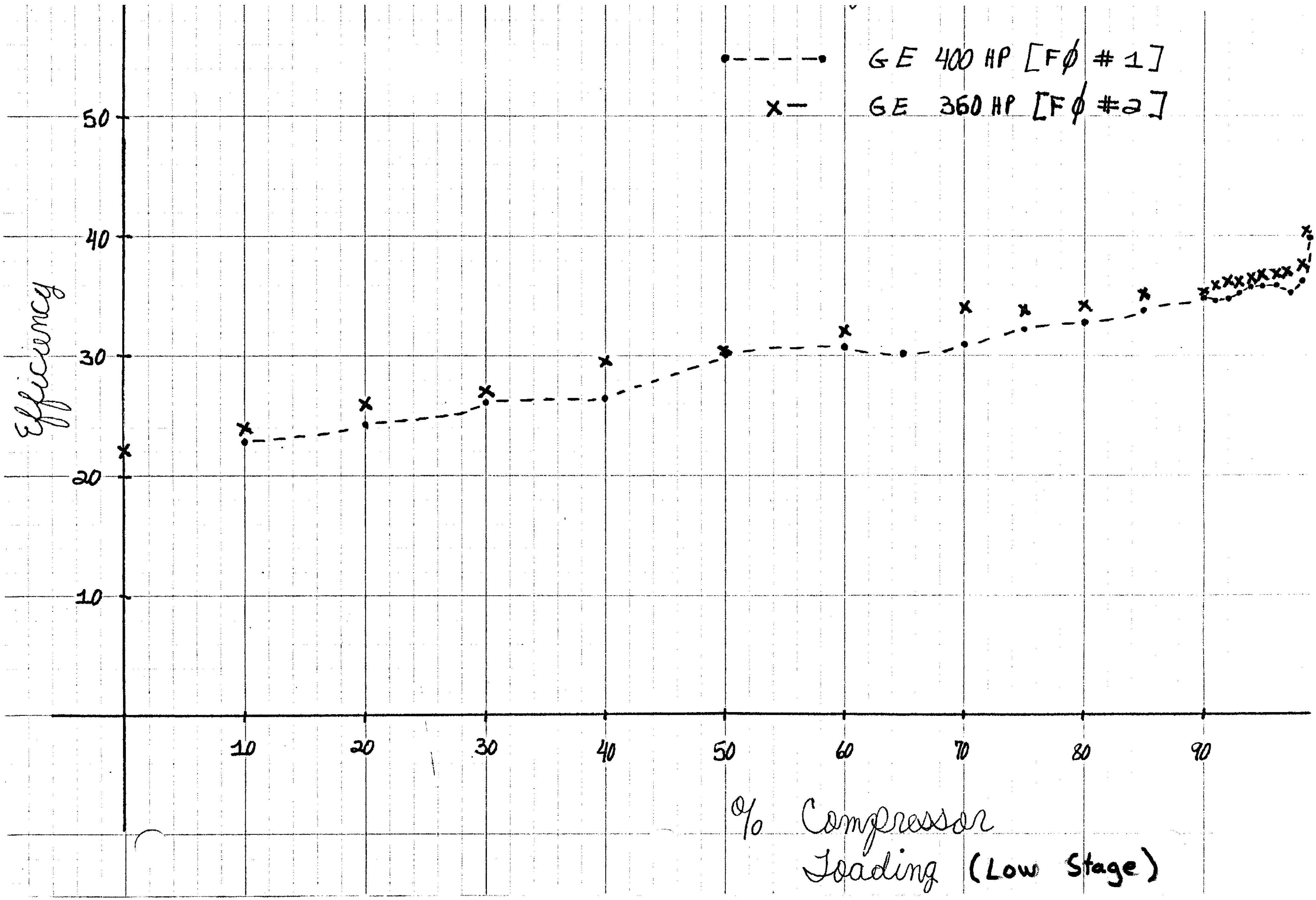


FIGURE 3

Compressor Isothermal Efficiency vs. Percent Loaded



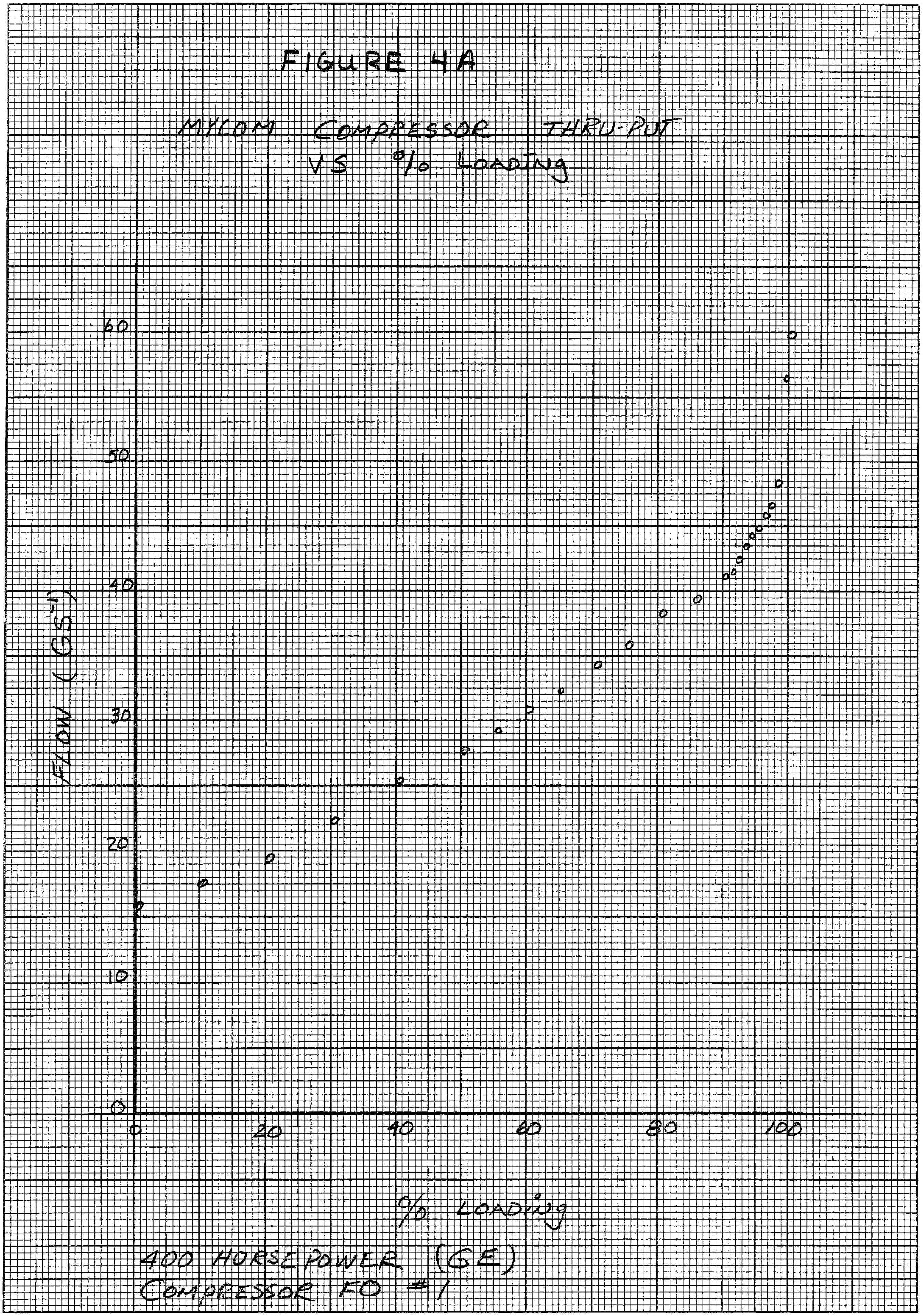


FIGURE 4A
MYCOM COMPRESSOR THRU-PUT
VS % LOADING
FLOW (GS⁻¹)
0
10
20
30
40
50
60
0
20
40
60
80
100
% LOADING
400 HORSEPOWER (GE)
COMPRESSOR FO #1

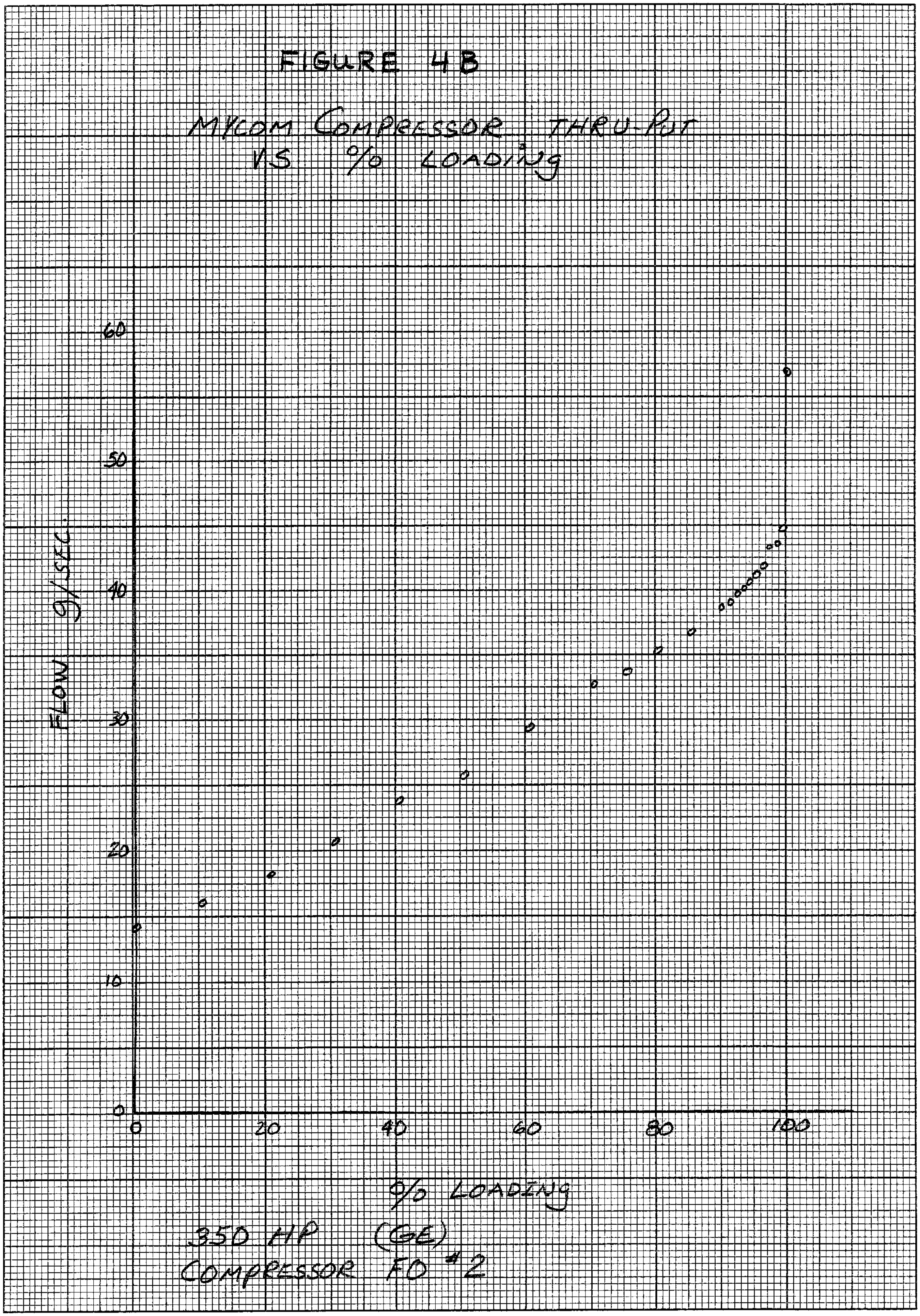


FIGURE 4B
MYCOM COMPRESSOR THRU-PUT
VS % LOADING
FLOW g/SEC.
60
50
40
30
20
10
0
0
20
40
60
80
100
% LOADING
350 HP (GE)
COMPRESSOR FO #2

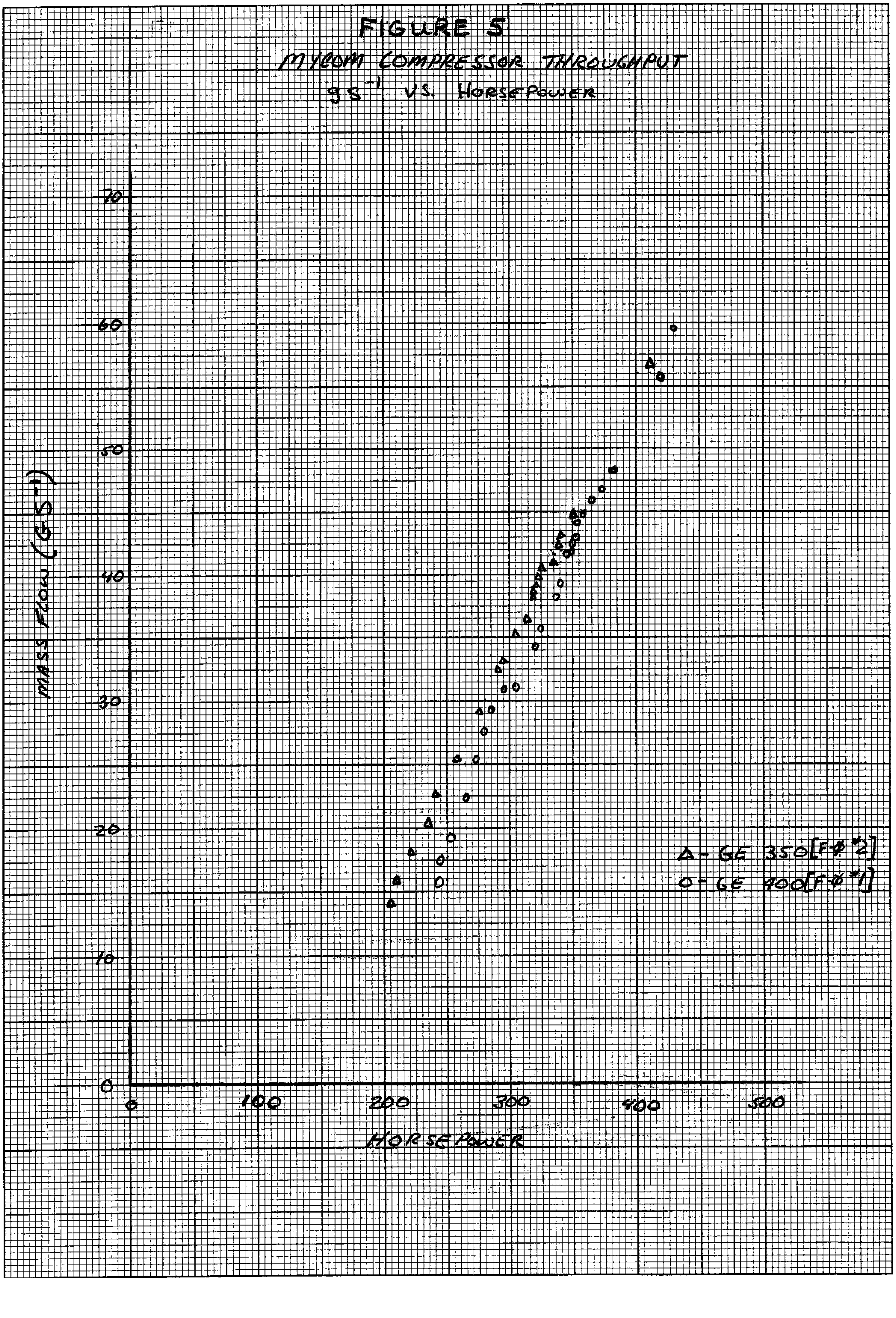


FIGURE 5
MYCOM COMPRESSOR THROUGHPUT
gs^{-1} VS. HORSEPOWER
MASS FLOW (G-S^{-1})
0
10
20
30
40
50
60
70
0
100
200
300
400
500
HORSEPOWER
Δ - GE 350[F-Ø #2]
O - GE 400[F-Ø #1]